AD-A088 099 AIR FORCE AEROSPACE MEDICAL RESEARCH LAB WRIGHT-PATT--ETC F/G 6/17
HEARING PROTECTION AND SPEECH COMMUNICATION CHARACTERISTICS OF --ETC(U)
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LEVEL II

HEARING PROTECTION AND SPEECH COMMUNICATION CHARACTERISTICS OF SELECTED USAF INFLIGHT HELMETS

MARK R. STEPHENSON
DONALD E. TONELLI

Technical rept.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AMRL-TR-80-37	2. GOVT ACCESSION NO. AD-A088 079	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HEARING PROTECTION AND SPEECH COMMUNICATION CHARACTERISTICS OF SELECTED USAF INFLIGHT HELMETS		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mark R. Stephenson Donald G. Tomerlin		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Aerospace Medical Research Laboratory Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F, 7231-08-11
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE June 1980
		13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ear Protection
Speech Communication
Sound Attenuation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Hearing protection and speech intelligibility were measured on three widely used flight helmets: the HGU-26/P with standard earcups, HGU-26/P with custom earcups and the DH-151. The following results were obtained: (1) Attenuation tests demonstrated the DH-151 and the standard HGU-26/P generally provide equivalent hearing protection with the former providing somewhat greater protection at the low and high frequencies, but the latter providing somewhat greater protection at the middle frequency region. The custom HGU-26/P provided

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) less hearing protection than both of the above. (2) Replacing earcup assemblies with standard MX8376/AR earcups resulted in equal or improved hearing protection for the HGU-26/P helmet. In the DH-151 helmet, this resulted in less protection at the lower frequencies, but improved protection in the middle frequency range, and no change in the higher frequency range. (3) Speech intelligibility was determined by calculating the articulation index. Both the standard HGU-26/P and the DH-151 provide excellent speech intelligibility. The custom HGU-26/P was found to provide less speech intelligibility than the other two helmets. Never-the-less, we believe it would also permit adequate inflight speech communication.

SUMMARY

Hearing protection and speech intelligibility were measured on three widely used flight helmets: the HGU-26/P with standard earcups, HGU-26/P with custom earcups and the DH-151. The following results were obtained: (1) Attenuation tests demonstrated the DH-151 and the standard HGU-26/P generally provide equivalent hearing protection with the former providing somewhat greater protection at the low and high frequencies, but the latter providing somewhat greater protection at the middle frequency region. The custom HGU-26P provided less hearing protection than both of the above. (2) Replacing earcup assemblies with standard MX8376/AR earcups resulted in equal or improved hearing protection for the HGU-26/P helmet. In the DH-151 helmet, this resulted in less protection at the lower frequencies, but improved protection in the middle frequency range, and no change in the higher frequency range. (3) Speech intelligibility was determined by calculating the articulation index. Both the standard HGU-26/P and the DH-151 provide excellent speech intelligibility. The custom HGU-26/P was found to provide less speech intelligibility than the other two helmets. Never-the-less, we believe it would also permit adequate inflight speech communication.

A

PREFACE

This work was conducted in the Biological Acoustics Branch of the Biodynamic and Bioengineering Division, Air Force Aerospace Medical Research Laboratory. The effort was performed in support of work unit 72310811, "Hearing Protector Evaluation Performance and Methodology." The authors are greatful to Mr. John Hochwalt of the Aeronautical Systems Division, Life Support System Program Office's Engineering Group (ASD/AELE), and to Mr. Don Lowe of Systems Research Laboratories, Inc., for their assistance in fitting the helmets. Mrs. Hazel F. Watkings of the Biological Acoustics Branch is acknowledged for her help in preparation of the original manuscript.

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INTRODUCTION AND BACKGROUND

The Biological Acoustics Branch is responsible for evaluating the sound attenuation characteristics of all types of hearing protectors, including flight helmets. As hearing protection devices are modified or new devices come into use, it is necessary to revise the existing sound attenuation data. The hearing protection of devices for which sound attenuation has not been measured is sometimes estimated from the measured data of similar protectors, however, these estimated values are not sufficiently accurate to permit the calculation of allowable exposure durations. Sound attenuation measurements must be included in the evaluation of all (new and/or modified) protectors.

The sound attenuation characteristics of Air Force flight helmets must be defined to determine the degree of protection from hazardous noise exposure afforded to aircrew members during inflight operations. The sound attenuation values are subtracted from the inflight spectrum levels of the noise, and the limiting noise exposure durations are estimated for that particular operation. These measured attenuation values must be accurately determined because allowable exposure durations (i.e., "safe" noise exposures) for a particular noise environment will depend on the sound attenuation of the helmet.

Currently, three flight helmets are in general widespread use throughout the Air Force:

- HGU-26/P with MX 8376/AR earcups (usually referred to as the standard helmet)

- HGU-26/P with custom liner and custom fit leather covered foam earcups (also called pillow-block earcups, and usually referred to as the custom helmet)

- DH-151.

While both the standard and custom helmets have been in the Air Force inventory for several years, some changes have been made in the fabrication of each. Examples of these changes follow. In the early to mid 1970s, the H-154 spring loaded earcup assembly (in the standard HGU-26/P helmet shell) was replaced by the H-154A earcup assembly (MX 8376/AR). When the standard helmet was evaluated by AMRL in the winter of 1975, it was provided to crew members with leather covered foam fitting pads instead of the leather covered poured foam liner, which is more common today. The custom helmet was developed by the Wright-Patterson AFB Physiological Training Unit in the late 1960s, and evaluated by AMRL during the summer of 1970. It was designed for use by flight crew members who could not obtain a satisfactory fit with the standard helmet/liner configurations then available. Originally, individuals requiring a custom fit helmet were sent to Wright-Patterson AFB Physiological Training Unit for measurement, fitting and fabrication of their helmet. More recently, the technology and skills necessary to fit and fabricate the custom helmet have been transferred to the Life Support shops at each base. Recent correspondence with flight crew members suggests that the local fabrication process of the custom helmets may be somewhat different from that originally developed at Wright-Patterson AFB. Specifically, such factors as earcushion material, the method used to cover the earcushion, edgeroll composition and fabrication and, the process for making crew member head molds for helmet liners may all have changed since the original custom helmet tests. Therefore, both the standard helmet and the custom helmet have undergone changes that could result in sound attenuation values different from those obtained during the original AMRL evaluation. Finally, the DH-151 has recently appeared in general use throughout the Air Force. It is procured from the manufacturer by the individual flight crew member at his own expense, but the sound attenuation has never been evaluated by the Air Force. Because of those factors just noted, the AFAMRL determined that an additional series of sound attenuation tests must be conducted to revalidate the present Air Force flight helmet's hearing protection capabilities.

The purpose of the present investigation was threefold to determine the following:

- Hearing protection characteristics of those flight helmets in general widespread use throughout the Air Force
- Effects (if any) of replacing the earcup assemblies in custom fit helmets with standard AF MX 8376/AR earcups
- Speech communication characteristics of each of the helmets.

METHODOLOGY

SUBJECTS

Thirty-six flight crew members from the Tactical Air Command volunteered to participate as test subjects. Eighteen of the subjects were selected from the 9th Air Force, and eighteen of the subjects were selected from the 12th Air Force. No more than four subjects were from the same wing. This helped assure that the subjects were representative of the larger Air Force population. Each subject was pretested at his base to insure his hearing threshold levels (HTLs) were in compliance with subject hearing requirements in the American National Standards Institute *Method for the Measurement of Real-Ear Protection of Hearing Protectors* (ANSI S3.19-1974).[1] Subject's HTLs were again measured when they reported to the laboratory for testing. As a precautionary measure, subjects were required to be free from any occupational or recreational noise exposure for at least 12 hours prior to the start of the tests. Each subject was otoscopically inspected to confirm that his ear canal and tympanic membrane were normal.

INSTRUMENTATION

Instrumentation used to measure hearing protection was assembled and calibrated in accordance with the ANSI S3.19-1974 procedure. Figure 1 illustrates a block diagram of the system. Basically, the output of a white noise generator is directed to a 1/3 octave band filter which both shapes the spectrum and allows 1/3 octave band signals to be selected by the experimenter. This output is then sent to an attenuator with which the experimenter can adjust the intensity of the signal in 1 db steps. A Grason Stadler 1701 clinical diagnostic audiometer and its auxilliary equipment is used to (a) shape the rise/decay time of the signal, (b) control the on/off time, (c) continuously increase or decrease the signal intensity and (d) continuously trace the subject's response on an X-Y plotter. Finally, the signal is sent to a McIntosh amplifier, which powers three banks of loudspeakers in the test chamber.

PROCEDURE

After confirmation of the subjects' hearing threshold levels, the sound attenuation of their helmets was measured. Each subject was tested with his own personal helmet. There were twelve subjects for each of the three basic types of helmet previously discussed. Sound attenuation measurements were conducted as follows. Subjects controlled a handswitch with which they could continuously increase or decrease the intensity of the pulsing test signal at a rate of 5 dB per second. The signal's intensity was adjusted by the subject to vary between "just audible" and "just inaudible." The subjects' responses were continuously recorded on an X-Y plotter, and thresholds were determined by estimating the point midway between the "just audible" and "just inaudible" excursions recorded on the plotter. Thresholds were determined for 1/3 octave band noises centered on the following frequencies: 125, 250, 500 Hz, and 1, 2, 3.15, 4, 6.3 and 8 kHz. Six threshold measurements were obtained at each frequency: three while the subject was wearing

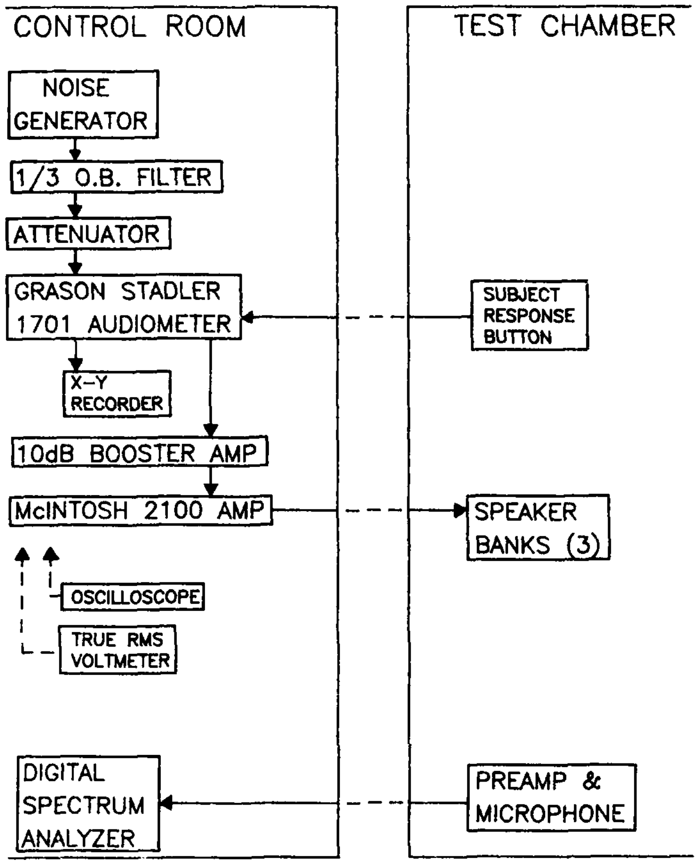

FIGURE 1. BLOCK DIAGRAM OF THE SYSTEM

the helmet, and three while the subject was not wearing the helmet. The difference between the "with helmet" and "without helmet" hearing thresholds is defined as the amount of sound attenuation provided by the helmet at each frequency. The greater the amount of sound attenuation (in decibels) the greater the hearing protection provided by the helmet.

RESULTS

HEARING PROTECTION

Table 1 contains the mean hearing protection and standard deviation values for each of the helmets tested. To more readily facilitate a comparison of these devices, the mean attenuation data are also shown in Figure 2. These data demonstrate that the DH-151 and the standard HGU-26/P generally provide equivalent hearing protection, with the former providing somewhat greater attenuation at the low and high frequencies, and the latter providing somewhat greater attenuation in the middle frequency region. The custom HGU-26/P provides less attenuation than either of the above at all frequencies tested. This relationship is further represented by the single number reduction values contained in Table 2. Single number reduction values are briefly described as a single number estimate of the amount of hearing protection a device will provide in a given noise environment. Single number reduction values are especially suitable for use when octave band analyses of specific work areas are not available; and the noise levels are defined in terms of "A" and "C" weighted sound measurements. The method used to calculate the single number reduction values has been described in detail elsewhere.[2] Currently, the Air Force calculates single number reduction values from sampling techniques and statistical measures of central tendency that yield the amount of hearing protection expected to be provided for 84% of the population wearing the hearing protector in question.

TABLE 1

MEAN REAL EAR ATTENUATION AND STANDARD DEVIATIONS FOR THREE AIR FORCE HELMETS

		FREQUENCY								
		125	250	500	1000	2000	3150	4000	6300	8000
Standard HGU-26/P	Atten.	6.9	6.1	14.2	22.3	32.6	43.3	44.1	39.5	37.5
	Std. Dev.	5.1	5.6	5.0	4.4	6.5	5.7	5.7	11.0	10.7
Custom HGU-26/P	Atten.	2.3	5.6	10.0	13.3	19.5	27.7	30.2	37.2	34.9
	Std. Dev.	5.8	5.4	5.2	5.1	7.2	7.8	9.5	7.4	5.5
DH-151	Atten.	10.3	12.7	18.5	20.3	29.6	34.2	39.4	42.0	41.4
	Std. Dev.	7.7	8.1	6.6	5.5	6.3	6.6	5.3	7.5	8.0

TABLE 2

SINGLE NUMBER REDUCTION VALUES

	dBC MINUS dBA VALUE				
HELMET	*-2 to 0*	*1 to 3*	*4 to 7*	*8 to 12*	*13 to 19*
Standard HGU-26/P	16	13	10	6	1
Custom HGU-26/P	11	9	6	3	-1
DH-151	17	15	12	9	4

An example of the application of the single number reduction values toward estimating the hearing protection of the flight helmets in question is described as follows. The single number reduction value is subtracted from the A-weighted sound level of a noise, to provide an estimate of the A-weighted sound level of the noise at the ear of a crew member wearing the particular hearing protection device. The noise exposure levels are then compared to the Air Force limiting noise levels in Table 3 of AFR 161-35[2] (Table 3 in this report is the same as Table 3 in AFR 161-35) to determine the allowable exposure. For example, in a noise environment measuring 106 dBC and 105 dBA, (C-A=1), the single number reduction values

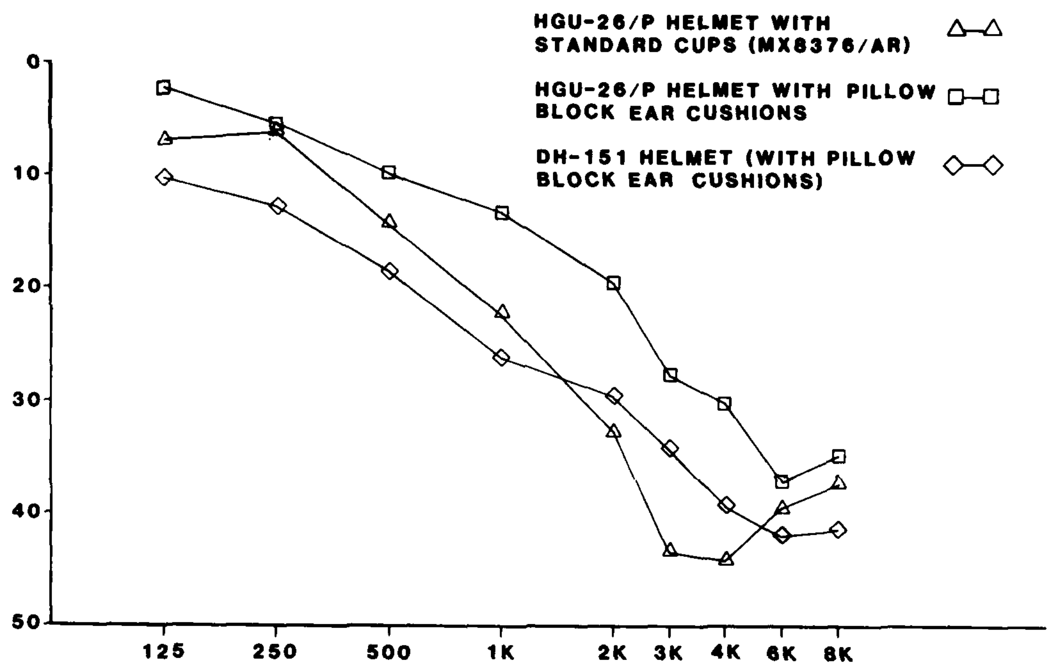

FIGURE 2. MEAN SOUND ATTENUATION

(C-A numbers derived from Table 2) are 13, 9 and 15 dB for the standard HGU-26/P, custom HGU-26/P and DH-151, respectively. When the single number reduction values are subtracted from the A-weighted noise level in question, (105 dBA in this case) the estimated level under the helmets would be 92, 96 and 90 dBA for each respective helmet. Finally, the allowable exposure duration for these noise levels may be calculated from Table 3. Thus, crew members would be allowed exposure durations of 2, 1 and 3 hours for the standard HGU-26/P, custom HGU-26/P and DH-151, respectively. The above example shows that each helmet could provide satisfactory hearing protection, depending on the length of the exposure. It also clearly demonstrates that under acoustically identical conditions, the custom HGU-26/P provides less protection than either of the other helmets tested. While the noise environment described above was chosen to approximate conditions encountered by crew members during cruise conditions for tactical aircraft,[3,4] the same method can be used to estimate permissible daily exposure for any noise environment.

TABLE 3

LIMITING VALUES FOR TOTAL DAILY EXPOSURE*

Duration of Total Daily Exposure	*Noise Level*
960 min	80 dBA
480 min	84 dBA
360 min	86 dBA
240 min	88 dBA
120 min	92 dBA
60 min	96 dBA
45 min	98 dBA
30 min	100 dBA
15 min	104 dBA
7.5 min	108 dBA
3.75 min	112 dBA
2.23 min	115 dBA

NOTE: The limiting duration of daily exposure at any noise level can be determined by the equation

$$\frac{16}{2^{(L-80)/4}}$$

*From Table 3, AFR 161-35[2]

EARCUP TYPE vs ATTENUATION

Previous evaluations conducted by this laboratory demonstrated that the Air Force helmet with the custom fit leather covered foam earcups provided less attenuation than the standard Air Force helmet with MX 8376/AR earcups. These results were generally confirmed by the present study. To evaluate the extent to which this difference was due to earcup type, twelve subjects who wore the Air Force custom helmet and twelve subjects who wore the DH-151 participated in additional attenuation tests. Specifically, the pillow block earcups were removed from their helmets, standard MX8376/AR earcups were inserted into the same helmets, and the attenuation tests were rerun. Thus, the independent variable was the earcup type, and any difference in attenuation may be attributed to earcup type. Figures 3 and 4 show the mean attenuation of the standard earcups compared to the custom earcups in the same helmet. Table 4 lists the same data in tabular form and Table 5 compares the single number reduction values. The data demonstrate that both helmets will provide better hearing protection between 1000 and 4000 Hz if standard earcups are worn in place of the "pillow block" earcups. and that both earcup types provide equivalent attenuation at 6 and 8 kHz. However, when the standard earcups are worn in place of the Protection Inc. "pillow block" earcups of the DH-151 *less* protection is provided from 125 to 500 Hz. These results mean that the hearing protection of the MX 8376/AR earcup will be equal to or better than protection provided by the "pillow block" earcup in the standard AF helmet. For pilots wearing the DH-151, the pillow block earcup provides more attenuation at the lower frequencies, while at the middle

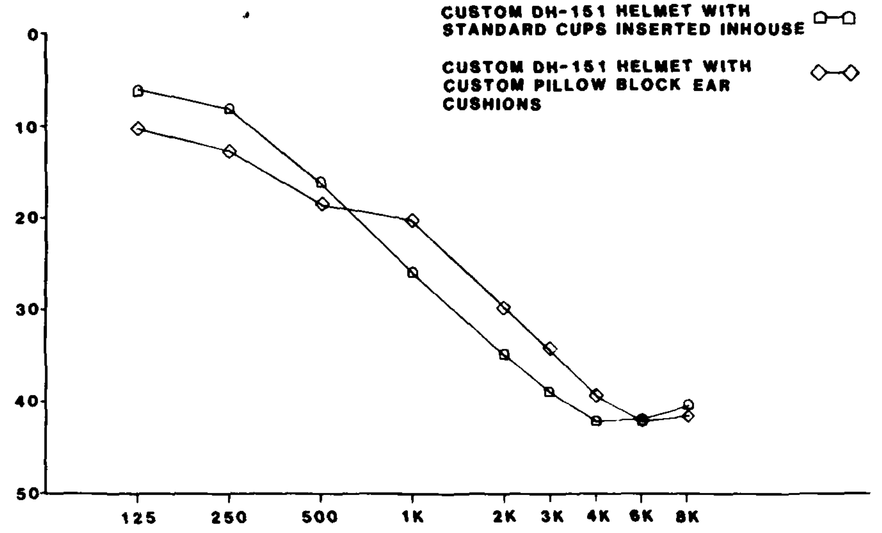

FIGURE 3. EARCUP TYPE vs ATTENUATION FOR THE DH-151 HELMET

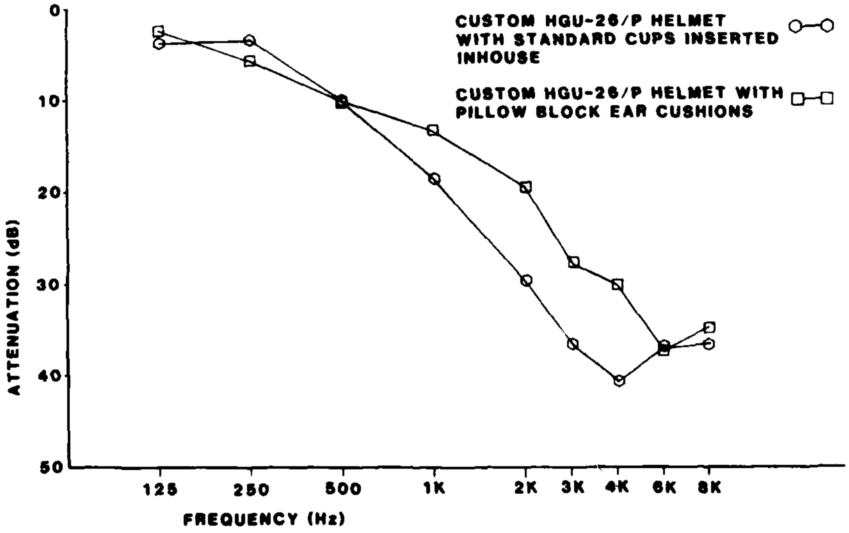

FIGURE 4. EARCUP TYPE vs ATTENUATION FOR THE HGU-26/P HELMET

frequencies, the MX 8376/AR earcup provides more attenuation. A comparison of the single number reduction values (Table 5) demonstrates small (2 dB or less) or no differences between earcup type and attenuation within the same helmet shell and liner. Therefore, while these differences are measurable, in many environments they may be of little practical significance.

TABLE 4

MEAN ATTENUATION OF MX8376/AR EARCUP VS MEAN ATTENUATION OF PILLOW BLOCK EARCUP

	Frequency (Hz)	125	250	500	1000	2000	3150	4000	6300	8000
HGU-26/P HELMET										
MX8376/AR	Attenuation	3.6	3.4	9.9	18.5	29.7	36.5	40.6	36.9	36.6
(Inserted Inhouse)	Std. Dev.	4.8	4.5	4.1	5.6	8.1	10.6	10.2	10.1	8.4
Pillow Block	Attenuation	2.3	5.6	10.0	13.3	19.5	27.7	30.2	37.2	34.9
	Std. Dev.	5.8	5.4	5.2	5.1	7.2	7.8	9.5	7.4	5.5
DH-151 HELMET										
MX8376/AR	Attenuation	6.0	8.0	16.1	25.9	34.9	38.9	42.0	41.9	40.4
(Inserted Inhouse)	Std. Dev.	5.1	4.8	4.6	7.4	6.7	9.4	8.6	7.4	7.5
Pillow Block	Attenuation	10.3	12.7	18.5	20.3	29.6	34.2	39.4	42.0	41.4
	Std. Dev.	7.7	8.1	6.6	5.5	6.3	6.6	5.3	7.5	8.0

TABLE 5

SINGLE NUMBER REDUCTION VALUES FOR MX8376/AR EARCUP VS SINGLE NUMBER REDUCTION VALUES FOR PILLOW BLOCK EARCUP

	dBC MINUS dBA VALUE				
	-2 to 0	1 to 3	4 to 7	8 to 12	13 to 19
HGU 26/P HELMET					
MX8376/AR (Inserted Inhouse)	13	10	7	4	-1
Pillow Block	11	9	6	3	-1
DH-151 HELMET					
MX8376/AR (Inserted Inhouse)	18	15	12	8	2
Pillow Block	17	15	12	9	4

Regardless of the earcup, the relationship of the amount of attenuation provided by each helmet remained constant. Specifically, the DH-151 always provided greater hearing protection at each of the frequencies tested. This possibly may be attributed to differences between helmet materials and the shape of the helmet shells. It is also likely to be related to the excellent workmanship of the Protection Inc. edgeroll and custom fitting of the liner and earcup. The best demonstration that the workmanship and fitting of the custom earcup and liner contributes to increased attenuation is shown by the superior low frequency attenuation of the Protection Inc. pillow block earcup. The attenuation data support observations by the experimenters in which the Protection Inc. custom liner and earcups seemed especially well shaped to the contours of the users' heads.

To improve an individual's hearing protection, thisLaboratory has previously suggested that selected individuals wearing the Air Force custom helmet replace their custom earcups with standard earcups. The data listed above confirm that this replacement will generally provide additional hearing protection. However, even this additional protection is still not equal to that provided by the standard helmet with standard earcups. Table 6 compares the attenuation of the standard helmet to the attenuation of a Laboratory modified custom helmet in which the custom earcups were removed and standard earcups were inserted. At every test frequency, the custom helmet modified to accept the standard earcup provides less attenuation than the standard helmet. Because this Laboratory modification of the earcups was conducted by or under the supervision of helmet experts of the Aeronautical Systems Division, Life Support Systems Program Office, fitting procedures are not seen as the reasons for the attenuation differences. Rather, the experimenters observed that when a standard earcup was inserted into a helmet with a liner previously configured for a custom earcup, the earcup did not neatly interface or abut with the liner. This underscores the importance of the workmanship in determining a custom helmet's hearing protection. Thus, the experimenters have concluded that if the user desires to replace a custom earcup with a standard earcup, he should also have an entirely new helmet liner/earcup combination fabricated for the helmet shell.

TABLE 6

ATTENUATION OF STANDARD HGU-26/P HELMET VS ATTENUATION OF CUSTOM HGU-26/P IN WHICH THE PILLOW BLOCK EARCUP WAS REMOVED, AND THE STANDARD (MX8376/AR) EARCUP WAS INSERTED IN THE LABORATORY

		FREQUENCY (Hz)								
		125	250	500	1000	2000	3150	4000	6300	8000
Standard HGU-26/P	Attenuation	6.9	6.1	14.2	22.3	32.6	43.3	44.1	39.5	37.5
	Std. Dev.	5.1	5.6	5.0	4.4	6.5	5.7	5.7	11.0	10.6
Custom HGU-26/P with	Attenuation	3.6	3.4	9.9	18.5	29.7	36.5	40.1	36.9	36.6
MX8376/AR Earcups	Std. Dev.	4.8	4.5	4.1	5.6	8.1	10.6	10.2	10.1	8.4

ARTICULATION INDEX

The hearing protection characteristics of Air Force flight helmets significantly interact with their speech communication capabilities in noise, consequently each helmet was rated for its voice communications effectiveness during simulated flight conditions. The method chosen to estimate each helmet's performance was the articulation index (AI). This is defined as "a weighted fraction representing, for a given speech and noise condition, the effective proportion of the normal speech signal available to a listener for conveying speech intelligibility."[5]

Actual voice communication tests such as the Modified Rhyme Test[6] provide a reasonably valid estimate of the voice communication characteristics of helmets since subjects are actually tested in realistic noise environments with their helmets and their associated inflight communication apparatus. When both subjects and helmets are available, communication evaluations are conducted as described in AMRL-TR-75-6, *Speech Communication Capability and Hearing Protection of USAF Inflight Headgear Devices.*[7] Unfortunately, time restraints on subject and helmet availability prevented the use of this type of communication evaluation, therefore, we decided to calculate the AI of each helmet.

There are several accpetable methods for calculating the AI. The calculation procedure we chose was the preferred frequency octave band method, described in *Methods for the Calculation of the Articulation Index*, American National Standard S3.5-1969.[5] The ambient noise (105 dBA) chosen for the AI calculations was based on cockpit noise measurements of tactical aircraft.[3,4] The actual noise level at the ear was determined by subtracting the attenuation of the flight helmet in question from the cockpit ambient noise. The speech spectra and levels chosen for the present calculations were based on inflight speech spectra measured at the ear, as transmitted through the standard AIC-25 inflight communication system. Because the AI of each helmet type was calculated on the basis of realistic cockpit and speech spectra, we are confident that the AI accurately predicts the general performance of the helmets and the AI also accurately permits a rank ordering of the communication effectiveness of each helmet type.

The AI for each helmet type is shown below. Table 7 contains not only the AI for each helmet, but also those values used in calculating the AI,

AI VALUES FOR EACH HELMET

Standard HGU-26/P	0.890
Custom HGU-26/P	0.646
Protection Inc. DH-151	0.872

To interpret the AI values, assume that an AI of 1.0 represents 100% intelligibility and an AI of 0 represents 0% intelligibility. Figure 5 (taken from ANSI S3.5-1969)[6] demonstrates the relationship between the AI and various measures of speech intelligibility. When the articulation indexes for both the standard HGU-26/P and the DH-151 are examined in the context of Figure 5, one would predict excellent inflight communication on the basis of the headgear and acoustic noise factors. This would be expected since AI's above 7.0 are considered appropriate even for communication systems in which adverse communication circumstances may be present.[6] The articulation indexes for both helmets clearly exceed this criterion. The AI for the custom HGU-26/P is less than 0.7, (0.646) but greater than 0.5. Thus, the American National Standard[6] would predict adequate speech intelligibility during general communication environments. However, during very adverse communication environments (such as might be encountered during combat or inflight emergencies), there is the possibility of marginal to unsatisfactory communication. Nevertheless, considering the training and experience of Air Force pilots, we are reasonably confident that adequate communications may be obtained with the custom HGU-26/P. Therefore, under routine operations, all of the helmets tested should provide adequate speech communication.

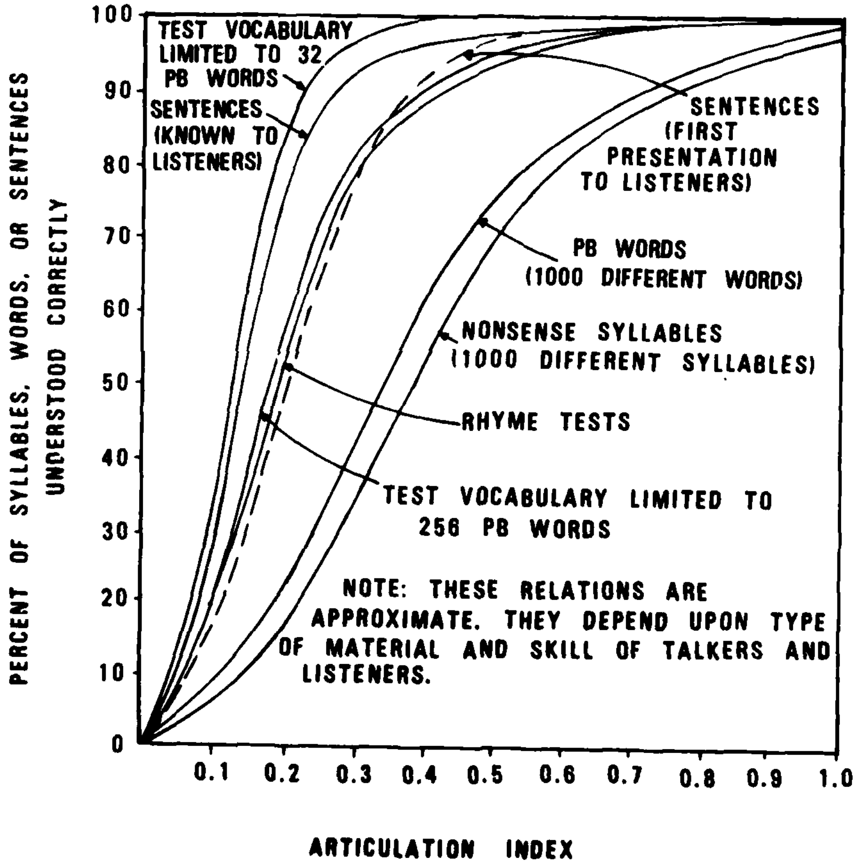

FIGURE 5. RELATION BETWEEN AI AND VARIOUS MEASURES OF SPEECH INTELLIGIBILITY

TABLE 7

ARTICULATION INDEX CALCULATION: PREFERRED FREQUENCY METHOD BASED ON 105 dBA AMBIENT NOISE LEVEL

HGU-26/P with MX 8376/AR Earcups

Center Frequency	Speech Level (dB)	Noise Level (dB)	Speech to Noise Ratio	Weighting Factor
250	87.3	86.8	0.5	0.00240
500	101.8	77.1	24.7	0.00480
1000	104.9	69.8	35.1	0.00740
2000	100.7	64.8	35.9	0.01090
4000	84.5	56.1	28.4	0.00780

ARTICULATION INDEX = 0.87216

DH-151

250	87.3	80.2	7.1	0.00240
500	101.8	72.8	29.0	0.00480
1000	104.9	71.8	33.1	0.00740
2000	100.7	68.1	32.6	0.01090
4000	84.5	63.1	21.4	0.00780

ARTICULATION INDEX = 0.87216

Custom HGU-26/P with Pillow Block Earcups

250	87.3	87.3	0.0	0.00240
500	101.8	81.3	20.5	0.00480
1000	104.9	78.8	26.1	0.00740
2000	100.7	77.9	22.8	0.01090
4000	84.5	70.9	13.6	0.00780

ARTICULATION INDEX = 0.64614

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